Changing Our Approach: Integrating Hydrologic Principles Into Stormwater Management and Site Design

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If we can use all of these...
Why do we always get these?

A Big Part of the Problem: We’ve Been Asking For It!

- We encourage them with our:
  - Stormwater Management Ordinances
  - Post-Construction Stormwater Management Criteria
What Are We Asking For?

Conventional SW Management Criteria

- Flood Control
  - 10-year, post- to pre-development
  - Etc.
- Channel Protection
  - Extended detention of 1-year, 24-hour storm
- Water Quality
  - Water Quality Volume
    - 90% of storms
    - First flush (0.5" or 1.0" of runoff)

Traditional Site Development Practices: LID

Aren't these systems intended to “lower the impact of the Development”?

- 1 or 2 structural BMPs
- 7 or 8 small-scale structural BMPs
- Numerous effective structural and non-structural BMPs
How am I supposed to inspect and maintain all this stuff??

Stormwater Criteria - Overview

- **Stormwater Quality**
  - Pollutant Load = Concentration (mg/l) x Volume (ft³)
  - Reduction = Reduction in Concentration AND/OR Reduction in Volume

- **Stormwater Quantity (Channel Erosion)**
  - Quantity translated into work (or energy);
  - Velocity, volume, duration, capacity
### Treatment Levels

**Current Requirements**

- **Load (lb/ac/yr)**: 0.25

**Proposed Requirements**

- **Load (lb/ac/yr)**: 0.45

**Additional Load Minimization**

- **Volume Reduction**
- **Pollutant Removal**

**Graph Points**

- **Required Level of Treatment**
- **Allowable Load (lb/ac/yr)**
- **Proposed Load (lb/ac/yr)**: 0.28
Runoff Reduction (RR) Method

- Codifies avoidance and minimization;
- Updated BMP specifications (Level 1 & 2), with volume reduction metric;
- Utilizes up to date science for nutrient reductions;
- Goes beyond impervious cover as a water quality indicator;
- Credits total BMP performance;
Volume Reduction: Runoff Hydrograph Modification

- Objective: Account for hydrologic effect of distributed retention storage;

- Simplifying Assumptions:
  - Assume retention is uniformly distributed if considering multiple features or sub-areas;
  - Assume negligible discharge from underdrains (if any)

Volume Reduction: Runoff Hydrograph Modification

Excerpted from work by Paul R. Koch, Ph.D., P.E.

Methods Considered:
1. Hydrograph Truncation
2. Hydrograph Scalar Multiplication
3. Precipitation Adjustment
4. Runoff Adjustment
5. Curve Number Adjustment
Runoff Hydrograph Modification

1. Hydrograph Truncation (Volume Diversion)

If the storage volume provided is less than the volume preceding the peak, there is no reduction in the peak, resulting in conservative design estimates of peak flow.

Runoff Hydrograph Modification

2. Hydrograph Scalar Multiplication

Reduction is applied along entire hydrograph instead of filling the retention storage at the beginning of the storm, potentially discounting the degree to which retention storage could reduce the peak.
Comparison of 2 methods that directly adjust hydrograph

Runoff Hydrograph Modification

Runoff Depth Equations (TR-55):

Where:
- \( Q \) = runoff depth (in)
- \( P \) = precipitation depth (in)
- \( S \) = potential maximum retention after runoff begins
- \( I_a \) = initial abstraction, volume that must be filled before runoff begins.

Additionally:

\[
I_a = 0.2S \\
S = \frac{1000}{CN} - 10
\]
3. Precipitation Adjustment:
Subtract Retention from Rainfall

\[ Q = \frac{(P - R - Ia)^2}{(P - R - Ia) + S} \]

Retention volume is never fully accounted for. Just as runoff is always less than rainfall, the change in runoff volume will always be less than the volume of retention provided when the retention volume is first subtracted rainfall before runoff depth is calculated.

4. Runoff Adjustment:
Subtract Retention from Runoff

\[ Q = \frac{(P - Ia)^2}{(P - Ia) + S} - R \]

This approach may accurately describe the response of the total site if the retention is uniformly distributed. However, neither TR-55 or TR-20 can be used to generate the resulting hydrograph.
NRCS Runoff depth formula solved for a new value of $S$, and then a revised CN value can be calculated from the revised $S$. No delay in the $T_c$ is reflected, and the reduction is distributed across the entire storm, resulting in a conservative estimate of the peak discharge.
Runoff Hydrograph Modification

Comparison of all 5 methods:

Runoff Reduction Method

Water Quality: Annual Volume Credit

- Virginia Water Quality Criteria: Annual load reduction (lb/ac/yr):
  - Pollutant Load = Volume (ft³) x EMC (mg/l)
  - Runoff Reduction Method (RRM) Spreadsheet

- Annual Volume and EMC Reduction based on research:
  BMP Specifications for Level 1 and Level 2
Runoff Reduction Method

Water Quantity:

- Annual Runoff Reduction Volume Credit;
  - RRM Spreadsheet

- Storm Specific Retention Volume Credit
  - Retention volume applied to TR-55 runoff equations for CN adjustment; or
  - Individual facility routing

Runoff Reduction Method

Water Quantity: Volume and Peak Rate Reduction

- 100% Impervious; CN = 98; TV = 3,448 ft³/ac
- Treat with Bioretention

<table>
<thead>
<tr>
<th>Design Storm</th>
<th>Level 1; CN Adj</th>
<th>Level 1; Vol Red</th>
<th>Level 2; CN Adj</th>
<th>Level 2; Vol Red</th>
<th>Retention Storage (TR-55) CN Adj</th>
<th>Retention Storage Vol Red</th>
<th>Routing Level 2 (No infiltration) Qpeak Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-yr</td>
<td>94</td>
<td>13%</td>
<td>90</td>
<td>27%</td>
<td>88</td>
<td>33%</td>
<td>35%</td>
</tr>
<tr>
<td>10-yr</td>
<td>95</td>
<td>7%</td>
<td>91</td>
<td>14%</td>
<td>90</td>
<td>18%</td>
<td>8%</td>
</tr>
</tbody>
</table>
Stormwater Quantity

Point of Discharge Options:

4VAC50-60-66.B Channel Protection
1. **Man-made** conveyance system:
   - $Q_2$ peak does not cause erosion

4VAC50-60-66.C Flood Protection
1. **Man-made** conveyance system:
   - $Q_{10}$ is within the system

Stormwater Quantity

Point of Discharge Options:

4VAC50-60-66.B Channel Protection
2. **Restored** conveyance system:
   - Post-developed peak will not exceed the design capacity of the system

4VAC50-60-66.C Flood Protection
2. **Restored** conveyance system:
   - Post-developed peak will not exceed the design capacity of the **system**
Stormwater Quantity

Point of Discharge Options:

4VAC50-60-66.B Channel Protection

3. **Stable Natural** conveyance system:
   i) will not become unstable during the 1-yr storm; and
   ii) 1-yr “energy balance” (Pre-Developed)

4VAC50-60-66.C Flood Protection

3. **Natural** conveyance system, No existing flooding:
   10-yr storm contained within the *system*
Stormwater Quantity

Point of Discharge Options:

4VAC50-60-66.B Channel Protection
4. **Unstable Natural** conveyance system:
   
   1-yr “energy balance” (Pasture\(^1\))

4VAC50-60-66.C Flood Protection
4. **Natural** conveyance system, with existing flooding:
   
   10-yr “energy balance” (Pasture\(^1\))

\(^1\) < 5ac land disturbance on Re-Dev.; < 1 ac New Dev: 1-yr & 10-yr Qpeak < Pre-Dev
Supporting Criteria

1. Flood Protection
2. Channel (Aquatic Resource) Protection
3. Water Quality Protection
4. Stormwater Runoff Reduction
5. Natural Resources Inventory & Use of Green Infrastructure Practices

Nested Approach to Stormwater Sizing Criteria
What stormwater management practices can be used to comply with these criteria?

Natural Resources Inventory

- Aquatic Resources: Perennial and intermittent streams, wetlands, groundwater recharge areas, buffers, etc.
- Topography: Natural drainage divides, patterns and features (e.g., swales, basins, depressional areas)
- Soils: porous & erodible soils,
- Trees and other existing vegetation
Runoff Reduction Method
Technical Memorandum; April, 2008

3 Step Compliance

Runoff Reduction (RR) Method: 3 Step Compliance

- Step 1: Apply environmental Site Design (ESD)
- Step 2: Apply Runoff Reduction (RR) Practices
- Step 3: Apply Pollutant Removal (PR) Practices

Iterative Process

Reduce Treatment Volume & Phosphorus Load

Target Level & Limit Achieved?

Possible Step 4: Pay Offset Fee For Harvest 1 and (final Option)

Proceed to Site Stormwater & BMP Design

YES

NO
Runoff Reduction (RR)

Recent Studies: Runoff Reduction (Ave. = 75%)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Practice</th>
<th>Runoff Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diaz and Clausen, 2006</td>
<td>Bioretention</td>
<td>99</td>
</tr>
<tr>
<td>Van Seters et al., 2006</td>
<td>Bioretention</td>
<td>58</td>
</tr>
<tr>
<td>Rushion, 2002</td>
<td>Bioretention</td>
<td>98</td>
</tr>
<tr>
<td>Hunt et al., 2006</td>
<td>Bioretention</td>
<td>50</td>
</tr>
<tr>
<td>Smith and Hunt, 2006</td>
<td>Bioretention</td>
<td>40 - 60</td>
</tr>
<tr>
<td>UNHSC, 2006</td>
<td>Bioretention</td>
<td>75</td>
</tr>
<tr>
<td>Horn et al., 2003</td>
<td>Biofiltration Swale</td>
<td>98</td>
</tr>
<tr>
<td>Jefferies, 2004</td>
<td>Biofiltration Swale</td>
<td>94</td>
</tr>
<tr>
<td>Staggs, 2006</td>
<td>Biofiltration Swale</td>
<td>46 - 54</td>
</tr>
<tr>
<td>Rushion, 2002</td>
<td>Porous Pavement</td>
<td>75</td>
</tr>
<tr>
<td>Van Seters et al., 2006</td>
<td>Porous Pavement</td>
<td>99</td>
</tr>
<tr>
<td>Hunt and Lord, 2006</td>
<td>Porous Pavement</td>
<td>60 - 90</td>
</tr>
<tr>
<td>Jefferies, 2004</td>
<td>Porous Pavement</td>
<td>50</td>
</tr>
<tr>
<td>Cooches et al., 2004</td>
<td>Rainwater Harvesting</td>
<td>60 - 90</td>
</tr>
</tbody>
</table>

Runoff Reduction (RR) Practices

Table 6. Runoff Reduction for various BMPs (from Table 2)

<table>
<thead>
<tr>
<th>Practice</th>
<th>RR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Roof</td>
<td>45 to 60</td>
</tr>
<tr>
<td>Rooftop Disconnection</td>
<td>25 to 50</td>
</tr>
<tr>
<td>Rain tanks and Cisterns</td>
<td>40</td>
</tr>
<tr>
<td>Permeable Pavement</td>
<td>45 to 75</td>
</tr>
<tr>
<td>Grass Channel</td>
<td>10 to 20</td>
</tr>
<tr>
<td>Bioretention</td>
<td>40 to 80</td>
</tr>
<tr>
<td>Dry S</td>
<td>0</td>
</tr>
<tr>
<td>Wet S</td>
<td>0</td>
</tr>
<tr>
<td>Infiltrate</td>
<td>0</td>
</tr>
<tr>
<td>ED Pools</td>
<td>0</td>
</tr>
<tr>
<td>Soil A</td>
<td>0</td>
</tr>
<tr>
<td>Sheet flow to Open Space</td>
<td>20 to 75</td>
</tr>
<tr>
<td>Filtering Practice</td>
<td>0</td>
</tr>
<tr>
<td>Constructed Wetland</td>
<td>0</td>
</tr>
<tr>
<td>Wet Pond</td>
<td>0</td>
</tr>
</tbody>
</table>


Range of values is for Level 1 and Level 2 designs – see Section 9 & Appendix D
Pollutant Removal (PR) Practices

Table 7. EMC-based pollutant removal for various BMPs (from Tables 2 and 3)

<table>
<thead>
<tr>
<th>Practice</th>
<th>Total Phosphorus PR (%)</th>
<th>Total Nitrogen PR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Roof</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Disconnection</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rain tanks and Cisterns</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Permeable Pavement</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Grass Channel</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Dry Swale</td>
<td>40 to 60</td>
<td>25 to 35</td>
</tr>
<tr>
<td>Wet Swale</td>
<td>25 to 35</td>
<td></td>
</tr>
<tr>
<td>Infiltration</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>ED Pond</td>
<td>10</td>
<td></td>
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<tr>
<td>Soil Amendments</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Sheetflow to Open Space</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Filtering Practice</td>
<td>60 to 65</td>
<td>30 to 45</td>
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<tr>
<td>Constructed Wetland</td>
<td>50 to 75</td>
<td>25 to 55</td>
</tr>
<tr>
<td>Wet Pond</td>
<td>50 to 75</td>
<td>30 to 40</td>
</tr>
</tbody>
</table>

Range of values is for Level 1 and Level 2 designs – see Section 9 & Appendix D

Multi-Function Practices

<table>
<thead>
<tr>
<th>Practice</th>
<th>Site Design</th>
<th>Runoff Reduction</th>
<th>Pollutant Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rooftop Disconnection</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>2. Filter Strip</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>3. Grass Channel</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>4. Soil Amendment</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>5. Green Roof</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Rain Tanks &amp; Cisterns</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Permeable Pavement</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>8. Infiltration</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>9. Bioretention</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>10. Dry Swales</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>12. Filtering Practices</td>
<td>✔</td>
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<tr>
<td>13. Constructed Wetlands</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Wet Ponds</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. ED Ponds</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>
Stormwater Design Specifications

Section 1: Description

- Table 1: Summary of Stormwater Functions
  - Runoff Reduction: Level 1 – 40%; Level 2 – 80%
  - Total Phosphorus Removal: Level 1 – 25%; Level 2 – 50%
  - Total Nitrogen Removal: Level 1 – 40%; Level 2 – 60%
  - Channel & Flood Protection: Use RRM Spreadsheet to calc CN adj.
    Design extra storage (optional as needed) to accommodate larger storm;
    NRCS TR-55 Runoff Eq to compute CN Adjustment

Section 2: Level 1 & Level 2 Design Tables

- Sizing
- Maximum/Minimum drainage area
- Surface area/Drainage Area ratios
- Soil Testing Requirements
- Geometry
- Pre-Treatment
- Conveyance and Overflow
- Building Setbacks
Stormwater Design Specifications

Section 3: Typical Details

Section 4: Physical Feasibility and Design Applications
- Available Space
- Topography
- Hydraulic Head
- Water Table
- Soils
- Contributing Drainage Area
- Hotspot Land Uses
- Floodplains
- Roads/Parking lots/Commercial/Residential
- Retrofitting
Stormwater Design Specifications

- Section 5: Design Criteria
  - Stormwater Quality
  - Stormwater Quantity

- Section 6: Regional and Special Case Design Adaptations
  - Karst Terrain
  - Coastal Plain
  - Steep Terrain
  - Winter Performance
  - Linear Highway

- Section 7: Construction Sequence and Inspection

- Section 8: Maintenance
  - Maintenance Agreements
  - First Year Maintenance Inspections
  - Routine/Non-Routine Maintenance
  - Steep Terrain
  - Winter Performance
  - Linear Highway

- Section 9: Design References
Design Specification No. 1: Rooftop (Impervious) Disconnection

- Minimum Criteria: DA; Length; Slope
- Alternative Practices
  - Soil Compost Amended Filter Path
  - Dry Well of French Drain
  - Rain Garden (Micro-Bioretention)
  - Rainwater Harvesting
  - Stormwater Planter (Urban Bioretention)

Runoff Reduction (RR): L1 = 25% to 50%; Pollutant (Nutrient) Removal: 0
L2 = 50%

Design Specification No. 2: Filter Strips & Conservation Areas

- Need a Treatment Volume Design Storm
  - Engineered Level Spreaders
  - Intensity of 1”/hr
  - Q_{10} / 7
  - Consistent Application!!!!

RR: L1 = 25% to 50%; PR: 0
L2 = 50% to 75%
Design Specification No. 3: Grass Channels

RR: L1 = 10% to 20%; PR: TP = 15%; TN = 20%

Design Specification No. 4: Soil Amendments

- Minimum Criteria
- IC:CA
  - Depth of compost
  - Depth of Incorporation
  - Erosion Control

Compost Amendments are used to decrease runoff coefficient; or Enhance the RR and PR of other practices: grass channels, disconnection, etc.
Design Specification No. 5: Green Roof

- Energy savings
- Added living space
- Stormwater retention
- Urban heat island reduction
- Extended roof life – anecdotal evidence from Germany shows 2-3 X roof life, from 20 to 40-60 years.
- Aesthetics – viewscape
- Potential Water Quality Improvement
Construction Costs on a PER ACRE TREATED BASIS

<table>
<thead>
<tr>
<th>Bioretention</th>
<th>Green Roof</th>
<th>Wetland</th>
</tr>
</thead>
<tbody>
<tr>
<td>$14K - $44K</td>
<td>$650K - $1.1M</td>
<td>$800 - $7K</td>
</tr>
</tbody>
</table>

Design Specification No. 6: Rainwater Harvesting

- Need to define water budget
  - Interior use
  - Seasonal irrigation
  - Year round irrigation
  - Combination

RR: L1 = 15% to 60%; PR: 0
L2 = 45% to 90%
Design Specification No. 7: Permeable Pavement

- Permeable Concrete
- Permeable Asphalt
- Interlocking Pavers

RR: L1 = 45%; PR: TP = 25%; TN = 25%
L2 = 75%; PR: TP = 25%; TN = 25%

Design Specification No. 8: Infiltration

- Trench; or Basin
- Soil Testing
- DA Size
- Pre-treatment

Infiltration Trench That Could!

RR: L1 = 50%; PR: TP = 25%; TN = 15%
L2 = 90%; PR: TP = 25%; TN = 15%
Design Specification No. 9: Bioretention

- Bioretention Level 1; Level 2
- Micro-Bioretention (Rain Garden)
- Sizing: $SA (\text{ft}^2) = TV (\text{ft}^3) / \text{storage depth(ft)}$

<table>
<thead>
<tr>
<th>Level</th>
<th>SA ($\text{ft}^2$)</th>
<th>TV ($\text{ft}^3$)</th>
<th>Storage Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td></td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>Level 2</td>
<td></td>
<td></td>
<td>1.65</td>
</tr>
</tbody>
</table>

RR: L1 = 40%; PR: TP = 25%; TN = 40%
L2 = 80%; PR: TP = 50%; TN = 60%

Design Specification No. 10: Dry Swale

- Dry Swale
- Bio Swale

RR: L1 = 40%; PR: TP = 20%; TN = 25%
L2 = 60%; PR: TP = 40%; TN = 35%
Design Specification No. 11: Wet Swale

- RR: L1 = 0%; PR: TP = 20%; TN = 25%
- L2 = 0%; PR: TP = 40%; TN = 35%

Design Specification No. 12: Filtering Practices

- Longevity;
- Maintenance;
- Proprietary Devices
- Bioretention Filter?

- RR: L1 = 0%; PR: TP = 60%; TN = 30%
- L2 = 0%; PR: TP = 65%; TN = 45%
Design Specification No. 13: Constructed Wetland

RR: L1 = 0%; PR: TP = 50%; TN = 25%
L2 = 0%; PR: TP = 75%; TN = 55%

Design Specification No. 14: Wet Ponds

RR: L1 = 0%; PR: TP = 50% (45%1); TN = 30% (20%1)
L2 = 0%; PR: TP = 75% (65%1); TN = 40% (30%1)

1 Lower value in parentheses apply to wet ponds in the coastal plain.
Design Specification No. 14: Wet Ponds

- Greater use of trees and natural landscaping in buffers, benches and islands
- Tougher enforcement on forebays, benches, sideslope and other pond geometry criteria
- Keep pool depths around 4 to 6 feet
- Multiple cells or long flow paths
- Require landscaping plan to create more natural design
- Maintenance plan should emphasize vegetation management (avoid creating turf)
- Carefully assess environmental risks (stream warming, tree loss, wetlands, mosquito habitat, etc.)

Design Specification No. 15: Extended Detention Ponds

RR: L1 = 0%; PR: TP = 15%; TN = 10%
L2 = 15%; PR: TP = 15%; TN = 10%
QUESTIONS??